

CERTIFICATION REPORT

The certification of the absorbed energy (150 J nominal) of Charpy V-notch reference test pieces for tests at 20 °C: ERM[®]-FA415ab

European Commission
Joint Research Centre
Institute for Reference Materials and Measurements

Contact information

Reference materials sales
Retieseweg 111
B-2440 Geel, Belgium
E-mail: jrc-irrm-rm-sales@ec.europa.eu
Tel.: +32 (0)14 571 705
Fax: +32 (0)14 590 406

<http://irrm.jrc.ec.europa.eu/>
<http://www.jrc.ec.europa.eu/>

Legal Notice

Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

Europe Direct is a service to help you find answers to your questions about the European Union
Freephone number (*): 00 800 6 7 8 9 10 11
(*) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server <http://europa.eu/>

JRC 85184

EUR 26239 EN

ISBN 978-92-79-33891-5

ISSN 1831-9424

doi:10.2787/84027

Luxembourg: Publications Office of the European Union

© European Union, 2013

Reproduction is authorised provided the source is acknowledged

Printed in Belgium

CERTIFICATION REPORT

The certification of the absorbed energy (150 J nominal) of Charpy V-notch reference test pieces for tests at 20 °C: ERM[®]-FA415ab

G. Roebben, A. Dean, A. Lamberty

European Commission, Joint Research Centre,
Institute for Reference Materials and Measurements (IRMM), Geel, Belgium

Disclaimer

Certain commercial equipment, instruments, and materials are identified in this paper to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the European Commission, nor does it imply that the material or equipment is necessarily the best available for the purpose.

Summary

This certification report describes the processing and characterisation of ERM[®]-FA415ab, a batch of Charpy V-notch certified reference test pieces certified for the absorbed energy (*KV*) for tests at 20 °C. Sets of five of these test pieces are used for the verification of pendulum impact test machines according to ISO 148-2 (Metallic materials - Charpy pendulum impact test – Part 2: Verification of testing machines [1]).

The absorbed energy (*KV*) is procedurally defined and refers to the impact energy required to break a V-notched test piece of standardised dimensions, as defined in ISO 148-1 [2]. The certified value of ERM[®]-FA415ab is traceable to the SI, via the SI-traceable certified value of the master batch ERM-FA415s, by testing samples of ERM[®]-FA415ab and ERM[®]-FA415s under repeatability conditions on an impact pendulum verified and calibrated with SI-traceably calibrated tools. The certified value is valid only for strikers with a 2 mm tip radius. The certified values are valid at (20 ± 2) °C.

The certified values for *KV* (= energy required to break a V-notched test piece using a Charpy pendulum impact test machine) and the associated expanded uncertainties ($k = 2$ corresponding to a confidence level of about 95 %) calculated for the mean of a set of five test pieces, are:

Steel Charpy V-notch test pieces		
	Impact toughness	
	Certified value ²⁾ [J]	Uncertainty ³⁾ [J]
Absorbed energy (<i>KV</i>) at 20 °C ¹⁾	151	7
<p>1) The absorbed energy (<i>KV</i>) is a method defined measurand. <i>KV</i> is the impact energy required to break a V-notched bar of standardised dimensions, as defined in ISO 148-1. The certified value is valid only for strikers with a 2 mm tip radius, and in the temperature range of (20 ± 2) °C.</p> <p>2) The certified value of ERM-FA415ab, and the associated uncertainty, are traceable to the International System of Units (SI), via the master batch ERM-FA415s, of the same nominal absorbed energy (150 J) by testing samples of ERM-FA415ab and ERM-FA415s under repeatability conditions on an impact pendulum verified and calibrated with SI-traceably calibrated tools.</p> <p>3) Estimated expanded uncertainty of the mean <i>KV</i> of the 5 specimens (delivered as 1 set), with a coverage factor $k = 2$, corresponding to a level of confidence of about 95 %, as defined in ISO/IEC Guide 98-3, Guide to the expression of uncertainty in measurement (GUM:1995). The number of degrees of freedom of the certified uncertainty is $\nu_{RM} = 67$.</p>		

Table of contents

Summary	1
Table of contents	3
1 Introduction	7
1.1 <i>The Charpy pendulum impact test</i>	7
1.2 <i>The certification concept of Master Batch and Secondary Batch.....</i>	8
1.2.1 <i>Difference between Master and Secondary Batches</i>	8
1.2.2 <i>Certification of a Secondary Batch of Charpy V-notch test pieces</i>	8
1.2.3 <i>Uncertainty of the certified value of a Secondary Batch of Charpy V-notch test pieces</i>	9
2 Participants	9
3 Processing	9
3.1 <i>Processing of hot-rolled bars</i>	9
3.2 <i>Machining of Charpy test pieces</i>	10
3.3 <i>Heat treatment of hot-rolled bars.....</i>	10
3.4 <i>Final machining of Charpy test pieces</i>	10
3.5 <i>Quality control.....</i>	10
3.6 <i>Packaging and storage</i>	11
4 Homogeneity	11
5 Stability.....	11
6 Characterisation	12
6.1 <i>Characterisation tests</i>	12
6.2 <i>Data from Master Batch ERM-FA415s.....</i>	13
6.3 <i>Calculation of KV_{CRM} and of u_{char}</i>	13
7 Value assignment	14
7.1 <i>Certified value, combined and expanded uncertainty</i>	14
8 Metrological traceability and commutability	15
9 Instructions for use	16
9.1 <i>Safety information.....</i>	16
9.2 <i>Storage.....</i>	16
9.3 <i>Intended use.....</i>	16
9.4 <i>Sample preparation.....</i>	16
9.5 <i>Pendulum impact tests.....</i>	17
Acknowledgements	17
References	18
Annex 1	19
Annex 2.....	20

Glossary

AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
BCR	Community Bureau of Reference
CRM	Certified Reference Material
EC	European Commission
ERM [®]	European Reference Material
IMB	International Master Batch
IRMM	Institute for Reference Materials and Measurements
ISO	International Organization for Standardization
JRC	Joint Research Centre
k	Coverage factor
KV	Absorbed energy = energy required to break a V-notched test piece of defined shape and dimensions when tested with a pendulum impact testing machine
KV_{CRM}	Certified KV value of a set of 5 reference test pieces from the Secondary Batch
KV_{MB}	Certified KV value of the Master Batch test pieces
LNE	Laboratoire national de métrologie et d'essais
MB	Master Batch
n_{MB}	Number of samples of the Master Batch tested during certification of the Secondary Batch
n_{SB}	Number of samples of the Secondary Batch tested for certification
RSD	Relative standard deviation
s	Standard deviation
SB	Secondary Batch
s_h	Standard deviation of the results of the samples tested to assess the homogeneity of the Secondary Batch
s_{MB}	Standard deviation of the n_{MB} results of the samples of the Master Batch tested for the certification of the Secondary Batch

s_{SB}	Standard deviation of the n_{SB} results of the samples tested for the characterisation of the Secondary Batch
u_{CRM}	Combined standard uncertainty of KV_{CRM}
U_{CRM}	Expanded uncertainty ($k = 2$, confidence level of about 95 %) of KV_{CRM}
u_{char}	Standard uncertainty of the result of the characterisation tests
$u_{char,rel}$	Relative standard uncertainty of the result of the characterisation tests
u_h	Contribution to uncertainty from homogeneity
u_i	Value of uncertainty from contribution i
u_{MB}	Standard uncertainty of KV_{MB}
$u_{MB,rel}$	Relative standard uncertainty of KV_{MB}
\bar{X}_{MB}	Mean KV value of the n_{MB} measurements on samples of the Master Batch tested when characterising the Secondary Batch
\bar{X}_{SB}	Mean KV value of the n_{SB} results of the samples tested for the characterisation of the Secondary Batch
Δh	difference between the height of the centre of gravity of the pendulum prior to release and at the end of the half-swing during which the test sample is broken
ν_{RM}	Effective number of degrees of freedom associated with the uncertainty of the certified value

1 Introduction

1.1 The Charpy pendulum impact test

The Charpy pendulum impact test is designed to assess the resistance of a material to shock loading. The test, which consists of breaking a notched bar of the test material using a hammer rotating around a fixed horizontal axis, is schematically presented in Figure 1.

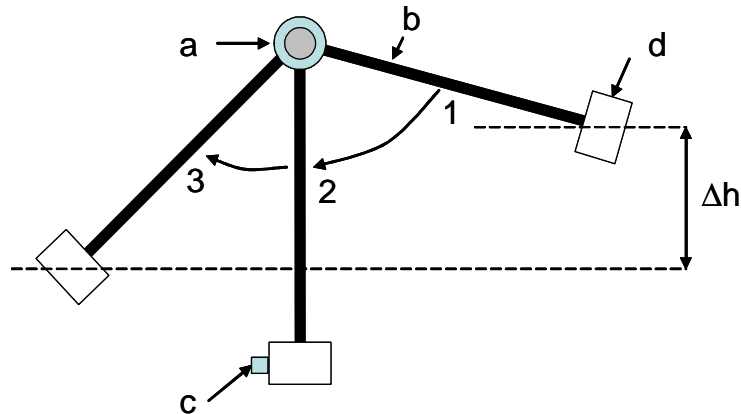


Figure 1: Schematic presentation of the Charpy pendulum impact test, showing a: the horizontal rotation axis of the pendulum, b: the stiff shaft on to which is fixed d: the hammer. The hammer is released from a well-defined height (position 1). When the hammer has reached maximum kinetic energy (shaft in vertical position 2), the hammer strikes c: the test sample, which is positioned on a support and against the pendulum anvils (not shown). The height reached by the hammer after having broken the sample (position 3) is recorded. The difference in height between position 1 and 3 (Δh) corresponds with a difference in potential energy, and is a measure of the energy required to break the test sample.

The energy absorbed by the test sample is very dependent on the impact pendulum construction and its dynamic behaviour. Methods to verify the performance of an impact pendulum require the use of reference test pieces as described in ISO and other international standards [1, 3]. The reference test pieces dealt with in this report comply with a V-notched test piece shape of well-defined geometry [1], schematically shown in Figure 2.

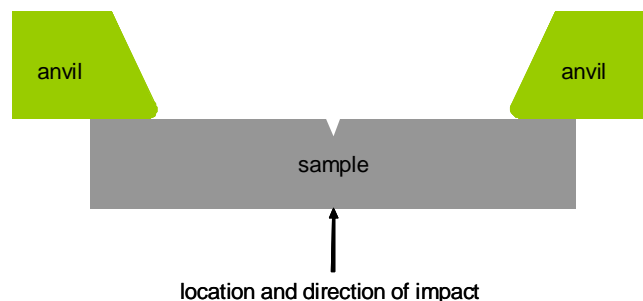


Figure 2: Schematic drawing of a V-notched Charpy test piece (top-view), indicating the place and direction of impact.

1.2 The certification concept of Master Batch and Secondary Batch

1.2.1 Difference between Master and Secondary Batches

The BCR reports by Marchandise et al. [4] and Varma [5] provide details of the certification of BCR “Master Batches” (MB) of Charpy V-notch certified reference test pieces. The certified value of a Master Batch is obtained using an international laboratory intercomparison.

This report describes the production of a “Secondary Batch” (SB) of Charpy V-notch certified reference test pieces at the Institute for Reference Materials and Measurements (IRMM) of the European Commission's (EC) Joint Research Centre (JRC). The work was performed in accordance with procedures described in the BCR reports [4] and [5]. The certification of a SB is based on the comparison of a set of SB test pieces with a set of test pieces from the corresponding MB under repeatability conditions on a single pendulum.

The BCR reports [4] and [5] were published in 1991 and 1999, respectively. Since 2000, the calculation of the certified value and the estimation of its uncertainty have been updated to an approach compliant with the ISO/IEC Guide to the Expression of Uncertainty in Measurement [6]. This revised approach was developed and presented by Ingelbrecht et al. [7, 8], and is summarised below.

1.2.2 Certification of a Secondary Batch of Charpy V-notch test pieces

The certified absorbed energy of a SB of Charpy V-notch reference test pieces (KV_{CRM}) is calculated from the mean KV -value of a set of SB-samples (\bar{X}_{SB}) tested on a single pendulum. This value \bar{X}_{SB} has to be corrected for the bias of this particular pendulum. The bias of the pendulum at the moment of testing the samples of the SB, is estimated by comparing the mean KV -value of a number of samples of the MB (\bar{X}_{MB}), tested together with the SB samples under repeatability conditions, with the certified value of the MB (KV_{MB}). KV_{CRM} is then calculated as follows [8]:

$$K_{V \text{ CRM}} = \left[\frac{K_{MB}}{\bar{X}_{MB}} \cdot \bar{X}_{SB} \right] \quad \text{Eq. 1}$$

For this approach to be reliable, the pendulum used for the tests on MB and SB in repeatability conditions, must be well performing. In other words, the ratio $\frac{KV_{MB}}{\bar{X}_{MB}}$ must be close to 1. IRMM allows a difference of 5 % ($KV_{MB} \geq 40 \text{ J}$) or 2 J ($KV_{MB} < 40 \text{ J}$) between KV_{MB} and \bar{X}_{MB} , corresponding with the level of bias allowed for reference pendulums specified in ISO 148-3 [9].

Also, for reasons of commutability, a comparable response of the pendulum to the MB and SB samples is required. This is the reason why MB and SB samples are made from nominally the same steel. Moreover, it is checked that the ratio $\frac{KV_{CRM}}{KV_{MB}}$ is close to 1. IRMM now allows a difference of 20 %

($KV_{MB} \geq 40$ J) or 8 J ($KV_{MB} < 40$ J) between KV_{CRM} and KV_{MB} to ensure that the MB and SB samples have a comparable interaction with the pendulum.

1.2.3 Uncertainty of the certified value of a Secondary Batch of Charpy V-notch test pieces

The uncertainty of the certified value of the SB is a combination of the uncertainties of the right-hand side factors in Eq. 1. It is clear that the MB-SB approach necessarily results in a larger uncertainty of the certified value of SB in comparison with the MB. The additional uncertainty depends on the uncertainty of the ratio $\bar{X}_{MB}/\bar{X}_{SB}$. The full measurement uncertainty of the values \bar{X}_{MB} and \bar{X}_{SB} is relatively large. However, when all conditions mentioned above (repeatability conditions, pendulum performance, and commutability between Secondary and Master Batch) are fulfilled, then the uncertainties of the values \bar{X}_{MB} and \bar{X}_{SB} have several contributions in common, in particular the uncertainty due to the bias of the pendulum. These shared uncertainty components do not contribute to the uncertainty of the ratio $\bar{X}_{MB}/\bar{X}_{SB}$, and only the standard deviations of the SB and MB results in the MB-SB comparison test need to be taken into account (see also Section 6.3). Thus, the MB-SB comparison approach can produce a value for the uncertainty of KV_{CRM} that is sufficiently small to meet the requirements of the intended use of the certified reference material (CRM).

2 Participants

The processing of the SB (ERM-FA415ab) test pieces was carried out by the Institut für Eignungsprüfung GmbH (IfEP), Marl (DE), using steel bars produced at Aubert&Duval, Les Ancizes (FR).

The MB samples (ERM-FA415s) used in the characterisation of the SB were provided by IRMM, Geel (BE).

The homogeneity of the SB was evaluated based on data obtained at IRMM using a pendulum verified according to the criteria imposed by ISO 148-2 [1].

Characterisation of the SB was carried out at IRMM using a pendulum verified according to the criteria imposed by ISO 148-2 [1]. The tests performed were within the scope of an ISO/IEC 17025 accreditation (BELAC 268-TEST).

Data evaluation was performed at IRMM. The certification project performed was within the scope of an ISO Guide 34 accreditation (BELAC 268-RM).

3 Processing

The ERM-FA415ab test pieces were prepared from ASTM 565 XM-32 steel. The steel was cast and rolled into bars at Aubert&Duval (see Section 3.1). Production of the test pieces from these bars was performed at IfEP (see Sections 3.2, 3.4, 3.2 and 3.6). During each step of the processing care was taken to randomise the sequence of the test pieces.

3.1 Processing of hot-rolled bars

The base material consisted of ASTM 565 XM-32 steel produced at Aubert&Duval. To limit the amount of impurities potentially affecting the homogeneity of the fracture resistance, the compositional tolerances specified

in Table 1 were imposed on the selected steel batch. These tolerances are stricter than generally allowed for ASTM 565 steel.

Table 1: Adapted composition tolerances of ASTM 565 Grade XM-32

Composition (mass fraction, in g/kg)						
C	S	P	Si	Mn	Cr	Ni
1.1 – 1.3	< 0.03	<0.18	1.5 – 3	7.5 – 9	112.5 – 116.5	25.5 – 27.5
Mo	Cu	Al	V	W	N	
15.5 – 17	< 2	< 0.1	2.5 – 3	< 1	0.25 - 0.4	

The ingot was hot rolled, resulting in bars that were 6 m long and with a squared cross-section of 12x12 mm. For the ERM-FA415ab batch, steel was used from ingot number HM156901.

3.2 Machining of Charpy test pieces

9 bars were cut into Charpy specimens by IfEP but not yet machined to the dimensional requirements of ISO 148-3 [9]. Each specimen was engraved to ensure identification and traceability.

3.3 Heat treatment of hot-rolled bars

The heat treatment of the specimens was performed at VTN Witten GmbH (DE) in a vacuum-furnace. All specimens were submitted to the following heat treatment:

Step 1: austenisation treatment at 1040 °C for 30 minutes

Step 2: quenching with nitrogen (8 bar)

Step 3: first tempering at 690 °C for 120 minutes

Step 4: cool down with nitrogen (8 bar)

Step 5: second tempering at 655 °C for 120 minutes

Step 6: cool down with nitrogen (8 bar).

The specimens were distributed over 3 baskets. The baskets were stacked in the furnace and each basket had three thermocouples to monitor the temperature homogeneity. The measured temperatures at all positions were within the tolerance of ± 6 °C as required by IfEP.

3.4 Final machining of Charpy test pieces

After heat treatment, the specimens were machined by IfEP to the final dimensions specified in ISO 148-3 [9]. During this process the specimen numbers were transferred to one of the end faces. Finally the specimens were notched using a milling process.

3.5 Quality control

When all samples from the batch were fully machined, a selection of 25 samples was made. The dimensions of the 25 samples were checked against the dimensional criteria specified in ISO 148-3 [9] (length $55.0^{+0.00}_{-0.30}$ mm, height 10.00 ± 0.06 mm, width 10.00 ± 0.07 mm, notch angle $45 \pm 1^\circ$, height remaining at notch root 8.00 ± 0.06 mm, radius at notch root 0.250 ± 0.025 mm, distance between the plane of symmetry of the notch and the longitudinal axis of the test piece 27.5 ± 0.2 mm). All samples were within the ranges specified in ISO 148-3 [9].

65 samples were selected for homogeneity control and impact tested using a pendulum Zwick PSW 750 (nominal energy 750 J), verified in May 2013 according to ISO 148-2 [1].

The tests were done on May 28, 2013. The results are reported in the production report of May 29, 2013 [10]. The average *KV* of the 65 samples was 154.0 J, which is within the desired energy range (142.5 J to 157.5 J). The standard deviation of the test results ($s = 5.8$ J, $RSD = 3.79$ %) was above the 3.3 % maximum promised by the contractor but <4% (maximum allowed by IRMM). The variation was checked again during the characterisation tests at IRMM (see Section 6).

3.6 Packaging and storage

Finally, the samples were cleaned and packed in sets of 5, in oil-filled and closed plastic bags. These oil-filled bags, together with a label, again were packed in a sealed plastic bag, and shipped to IRMM. After arrival (July 07, 2013) the 940 samples (or 188 sets) of ERM-FA415ab were registered and stored at room temperature, pending distribution.

4 Homogeneity

The test pieces are sampled from the SB, which is sufficiently, but not perfectly, homogeneous. Therefore, an appropriate homogeneity contribution u_h to the uncertainty of the certified value is required. u_h is related to s_h , the standard deviation between the samples in the SB (*sample-to-sample heterogeneity*), but also depends on the number of samples over which the *KV*-value is averaged. ISO 148-2 [1] specifies that the pendulum verification must be performed using 5 test pieces, which is why a CRM-unit consists of a set of 5 test pieces. The appropriate uncertainty contribution must be an estimate of the *set-to-set heterogeneity*, which in the case of a set of 5 test

pieces can be calculated as $u_h = \frac{s_h}{\sqrt{5}}$.

Here, u_h is estimated from s_h , the standard deviation of results of the characterisation obtained at IRMM on September 02, 2013 ($s_h = 5.7$ J). This

leads to $u_h = \frac{s_h}{\sqrt{5}} = 2.53$ J (or 1.62 %) [12].

As is required for a homogeneity test, the samples were randomly selected from the whole batch. The number of samples tested (50) is sufficiently large to reflect the homogeneity of the full SB (940 samples). It can be noted that u_h is probably a slight overestimation, since it contains also the repeatability of the instrument. However, the latter cannot be separated or separately measured.

5 Stability

The stability of the absorbed energy of Charpy V-notch certified reference test pieces was first systematically investigated for samples of nominally 120 J by Pauwels et al., who did not observe measurable changes of absorbed energy

[11]. Additional evidence for the stability of the reference test pieces produced from AISI 4340 steel of lower energy levels (nominally 15 J, 30 J and 100 J) has been obtained during the International Master Batch (IMB) project [13]. In the IMB-project, the stability of the certified test pieces was judged from the change of the mean of means of the absorbed energy obtained on 7 reference pendulums over a three year period. None of the three regression slopes for the tested energy levels was statistically significant at the 0.05 significance level. Given the large sample-to-sample heterogeneity and the limited number of samples (5) in a CRM unit, the uncertainty contribution from instability is considered to be insignificant in comparison to that of homogeneity.

The main reason for the microstructural stability of the certified reference test pieces is the annealing treatment to which the samples were subjected after the austenisation treatment. Annealing is performed at temperatures where the equilibrium phases are the same as the (meta-)stable phases at ambient temperature (α -Fe and Fe_3C). The only driving force for instability stems from the difference in solubility of interstitial elements in the α -Fe matrix, between annealing and ambient temperature. Relaxation of residual (micro-)stress by short-range diffusion or the additional formation or growth of precipitates during the shelf-life of the certified reference test pieces is expected to proceed but slowly.

In the meanwhile efforts are spent to better establish the stability of the certified values of batches of Charpy CRMs. Until such further notice, it is decided to specify a limited shelf-life. A period of 10 years is chosen, counting from the date of the characterisation tests on the SB. Since batch ERM-FA415ab was characterised in September, 2013, the validity of the certificate expires in September, 2023.

6 Characterisation

6.1 Characterisation tests

50 samples from the SB ERM-FA415ab (sets 5, 32, 51, 67, 97, 113, 125, 160, 171 and 185) were tested under conditions of repeatability with 25 samples from MB ERM-FA415s (sets 21, 63, 129, 210 and 234). The measurements were done using the Instron Wolpert PW 30 (serial number 7300 H1527) machine of IRMM, an impact pendulum yearly verified according to procedures described in ISO 148-2 [1]. Tests were performed on September 02, 2013 (test temperature 20 ± 1 °C), in accordance with ISO 148-1 [2]. The measurement sequence was: SB-MB-SB-MB-SB-MB-SB-MB-SB-MB-SB. The measured absorbed energy values were corrected for friction and windage losses.

The accepted data obtained on individual test pieces are shown in Figure 3 and Annex 1. The results of the measurements are summarised in Table 2.

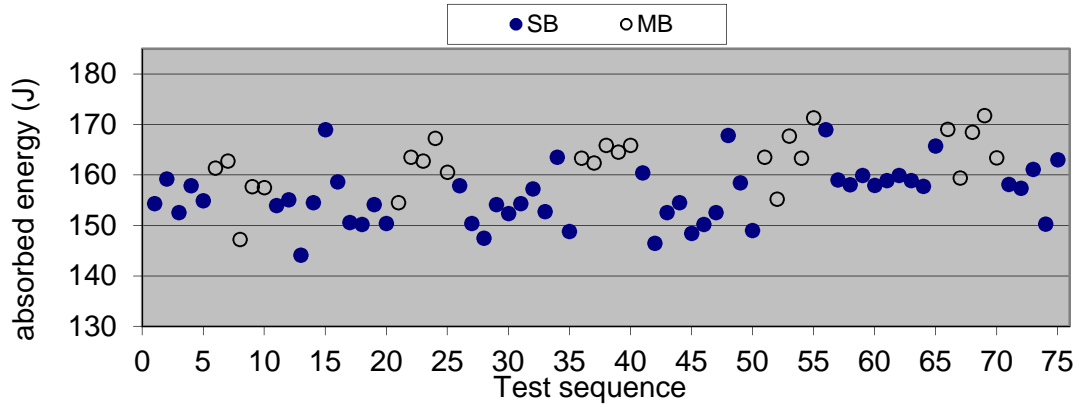


Figure 3: Absorbed energy values of 25 test pieces of ERM-FA415s compared with 50 test pieces of ERM-FA415ab; data are displayed in the actual test sequence.

Table 2: Characterisation measurements of Batch ERM-FA415ab

	Number of test pieces n_{MB}, n_{SB}	Mean value $\bar{X}_{MB}, \bar{X}_{SB}$ [J]	Standard deviation s_{MB}, s_{SB} [J]	Relative standard deviation RSD_{SB}, RSD_{MB} [%]
ERM-FA415s (MB)	25	162.83	5.53	3.40
ERM-FA415ab (SB)	50	155.89	5.66	3.63

The SB-results meet the ISO 148-3 acceptance criteria for a batch of reference materials ($s_{SB} < 5\%$ for $KV_{SB} > 40$ J).

6.2 Data from Master Batch ERM-FA415s

To calculate KV_{CRM} for ERM-FA415ab one needs KV_{MB} of the MB used, i.e. ERM-FA415s. Table 3 shows the main MB-data, taken from the Certificate of Analysis of ERM-FA415s (Annex 2).

Table 3: Data from the certification of Master Batch ERM-FA415s

	Certified absorbed energy of Master Batch KV_{MB} (J)	Standard uncertainty of KV_{MB} u_{MB} (J)	Relative standard uncertainty of KV_{MB} $u_{MB,rel}$ (%)
ERM-FA415s	157.3	1.4	0.89

6.3 Calculation of KV_{CRM} and of u_{char}

From the data in Tables 2 and 3, and using Eq. 1, KV_{CRM} can be calculated:
 $KV_{CRM} = 151$ J.

Rounding is done in accordance with uncertainty; see Table 4. The uncertainty associated with the characterisation of the SB, u_{char} , is assessed as in Eq. 2 [8], which sums the relative uncertainties of the three factors in Eq. 1:

$$u_{\text{char}} = KV_{\text{CRM}} \sqrt{\frac{u_{\text{MB}}^2}{KV_{\text{MB}}^2} + \frac{s_{\text{SB}}^2}{n_{\text{SB}} \cdot \bar{X}_{\text{SB}}^2} + \frac{s_{\text{MB}}^2}{n_{\text{MB}} \cdot \bar{X}_{\text{MB}}^2}} \quad \text{Eq. 2}$$

\bar{X}_{SB} and \bar{X}_{MB} were obtained under repeatability conditions. Therefore, the uncertainty of the ratio $\bar{X}_{\text{SB}} / \bar{X}_{\text{MB}}$ is not affected by the contributions from reproducibility and bias of the pendulum used to compare MB and SB. Table 4 summarises the input quantities of the u_{char} uncertainty budget, their respective statistical properties, and shows how they were combined.

The effective number of degrees of freedom (ν_{eff}) for u_{char} is obtained using the Welch-Satterthwaite equation from the combined uncertainty (u_c) and the individual uncertainty contributions (u_i) and their respective degrees of freedom (ν_i) (Eq. 3) [6].

$$\nu_{\text{eff}} = \frac{u_c^4}{\sum_{i=1}^N \frac{u_i^4}{\nu_i}} \quad \text{Eq. 3}$$

Table 4: Uncertainty budget for u_{char} for ERM-FA415ab

FA415ab	source of uncertainty	measured value (J)	standard uncertainty (J)	probability distribution	divisor	sensitivity coefficient	relative uncertainty (%)	degrees of freedom
KV_{MB}	Certification of MB	157.3	1.4	normal	1	1	0.89	6
\bar{X}_{SB}	comparison of SB and MB in repeatability conditions	155.89	0.80	normal	1	1	0.51	49
\bar{X}_{MB}		162.83	1.11	normal	1	1	0.68	24
$u_{\text{char,rel}}$ (%)							1.23	20
u_{char} (J)							1.85	

7 Value assignment

7.1 Certified value, combined and expanded uncertainty

As shown in 6.3, $KV_{\text{CRM}} = 151 \text{ J}$. The uncertainty of the certified value is obtained by combining the contributions from the characterisation study, u_{char} , and from the homogeneity assessment, u_{h} , as is summarised in the following uncertainty budget (Table 5).

The relevant number of degrees of freedom calculated using the Welch-Satterthwaite equation [6], is sufficiently large ($\nu_{\text{RM}} = 67$) to justify the use of a

coverage factor $k = 2$ to expand the confidence level to about 95 %. The obtained expanded uncertainty provides justification for the SB-MB approach followed: U_{CRM} is sufficiently smaller ($U_{CRM} = 4.1 \%$) than the verification criterion of 10 % for industrial pendulums [1] or even 5 % for reference pendulums [9].

Table 5: Uncertainty budget of KV_{CRM} for ERM-FA415ab

	source of uncertainty	relative value u_i (%)	degrees of freedom
u_{char}	characterisation of SB	1.23	20
u_{h}	homogeneity of SB	1.62	49
Combined standard uncertainty, u_{CRM} (%)			67
Combined standard uncertainty, u_{CRM} (J)			
Expanded Uncertainty, $k = 2$, U_{CRM} (%)			
Expanded Uncertainty, $k = 2$, U_{CRM} (J)			

8 Metrological traceability and commutability

The certified property is defined by the Charpy pendulum impact test procedure described in ISO 148-1 [2].

The certified value of the MB ERM-FA415s is traceable to the SI, since it was obtained using an interlaboratory comparison, involving a representative selection of qualified laboratories performing the tests in accordance with the standard procedures and using instruments verified and calibrated with SI-traceable calibration tools.

The certified value of ERM-FA415ab is made traceable to the SI-traceable certified value of the MB by testing SB and MB samples in repeatability conditions on an impact pendulum verified and calibrated with SI-traceably calibrated tools. Therefore, the certified value of ERM-FA415ab is traceable to the International System of Units (SI) via the corresponding Master Batch ERM-FA415s of the same nominal absorbed energy (150 J). Absorbed energy KV is a method-specific value, and can only be obtained by following the procedures specified in ISO 148-1 [2].

The intended use of the certified reference test pieces is the verification of Charpy impact pendulums. During the certification of the MB, different pendulums were used, each equipped with an ISO-type striker of 2 mm tip radius. Until further notice, the certified values are not to be used when the test pieces are broken with an ASTM-type striker of 8 mm tip radius [13].

9 Instructions for use

9.1 Safety information

Precautions need to be taken to avoid injury of the operator by broken specimens when operating the Charpy impact pendulum.

9.2 Storage conditions

Specimens should be kept at $(18 \pm 5) ^\circ\text{C}$ in their original packing until used. The European Commission cannot be held responsible for changes that happen during storage of the material at the customer's premises, especially of opened samples.

9.3 Intended use

Samples of ERM-FA415ab correspond to the 'certified reference test pieces' as defined in ISO 148-3 [9]. Sets of five of these certified reference test pieces are intended for the indirect verification of impact testing machines with a striker of 2 mm tip radius according to procedures described in detail in ISO 148-2 [1].

The indirect verification provides an assessment of the bias of the user's Charpy pendulum impact machine. This bias assessment can be used in the calculation of the measurement uncertainty of Charpy tests on the pendulum after indirect verification.

The certified value and associated uncertainty (given on page 1 of the certificate) are input parameters for this uncertainty assessment. In addition, when testing limited numbers of samples, the uncertainty calculation requires a check of the number of degrees of freedom, for which one needs the number of degrees of freedom of the certified uncertainty, ν_{RM} . In the case of ERM-FA415ab ν_{RM} is 67.

9.4 Sample preparation

Special attention is drawn to the cleaning of the specimens prior to the tests. It is mandatory to remove the oil from the sample surface prior to testing, without damaging the edges of the sample. Between the moment of removing the protective oil layer and the actual test, corrosion can occur. This must be avoided by limiting this period of time, while keeping the sample clean.

The following procedure is considered a good practice.

1. First use absorbent cleaning-tissue to remove the excess oil. Pay particular attention to the notch of the sample, but do not use hard (e.g. steel) brushes to remove the oil from the notch.
2. Submerge the samples in ethanol for about 5 min. Use of ultrasonication is encouraged, but only if the edges of the samples are prevented from rubbing against each other. To reduce the consumption of solvent, it is allowed to make a first cleaning step with detergent, immediately prior to the solvent step.

3. Once samples are removed from the solvent, only manipulate the samples wearing clean gloves. This is to prevent development of corrosion between the time of cleaning and the actual test.
4. Before testing, bring the specimens to the test temperature (20 ± 2) °C. To assure thermal equilibrium is reached, move the specimens to the test laboratory at least 3 h before the tests.

9.5 Pendulum impact tests

After cleaning, the 5 samples constituting a CRM-unit need to be broken with a pendulum impact test machine in accordance with ISO 148-1 [2] standards. Prior to the tests, the anvils must be cleaned. It must be noted that Charpy test pieces sometimes leave debris on the Charpy pendulum anvils. Therefore, the anvils must be checked regularly and if debris is found, it must be removed. The uncertainty of the certified value applies to the mean of the 5 KV-values.

Acknowledgements

The authors wish to thank M. Ricci, A. Held, R. Koeber, and H. Emons (all IRMM) for reviewing the certification report.

References

1. *ISO 148-2: Metallic materials - Charpy pendulum impact test - Part 2: Verification of testing machines*, International Organization for Standardization, Geneva (CH), 2008
2. *ISO 148-1: Metallic materials - Charpy pendulum impact test - Part 1: Test method*, International Organization for Standardization, Geneva (CH), 2009
3. *ASTM E23 - 07ae1 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*, ASTM International, West Conshohocken, PA (USA), 2007
4. Marchandise H., Perez-Sainz A., Colinet E., *Certification of the impact toughness of V-notch Charpy specimens*, in *BCR information series*, Community Bureau of Reference - BCR, Brussels (BE), 1991
5. Varma R.K., *The certification of two new master batches of V-notch Charpy impact toughness specimens in accordance with EN 10045-2: 1992*, CRM's 015 and 415, EUR Report 18947 EN - European Communities, Luxembourg - 1999 - ISBN 92-828-2244-3
6. *ISO/IEC Guide 98-3:2008, Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*, International Organization for Standardization, Geneva (CH), 2008
7. Ingelbrecht, C. and Pauwels J., *EC Reference Materials for Impact Toughness - Traceability and uncertainty*. Presentation at Eurachem Eurolab symposium on Reference Materials for Technologies in the New Millennium, Berlin, May 22-23, 2000
8. Ingelbrecht, C., Pauwels, J., and Gyppaz, D., *Charpy specimens from BCR for machine verification according to EN 10045-2*. Poster presentation at Charpy Centenary Conference, October 2-5, Poitiers (FR), 2001
9. *ISO 148-3: Metallic materials - Charpy pendulum impact test - Part 3: Preparation and characterization of Charpy V-notch test pieces for indirect verification of pendulum impact machines*, International Organization for Standardization, Geneva (CH), 2008
10. Production report : Charpy V-notch reference test pieces of 150 J nominal energy ERM-FA415ab, IfEP, Marl (DE), May 29, 2013
11. Pauwels, J., Gyppaz, D., Varma, R., Ingelbrecht, C., *European certification of Charpy specimens: reasoning and observations*, in *Pendulum Impact testing: A Century of Progress*. Seattle, Washington: American Society for Testing and Materials, 1999
12. IRMM Report of Analysis 2813, September 3, 2013
13. McCowan, C.N., Roebben, G., Yamaguchi, Y., Lefrançois, S., Splett, J. D., Takagi, S., Lamberty, A., *International Comparison of Impact Reference Materials (2004)*, J. ASTM International, Vol. 3(2), 2004

Annex 1

Results of characterisation measurements of ERM-FA415ab as measured according to ISO 148-1 at IRMM, September 02, 2013.

	Master Batch ERM-FA415s KV (J)	Secondary Batch ERM-FA415ab KV (J)
1	161.40	154.34
2	162.75	159.25
3	147.26	152.57
4	157.68	157.87
5	157.48	154.93
6	154.54	153.95
7	163.55	155.11
8	162.77	144.11
9	167.26	154.54
10	160.55	169.01
11	163.35	158.66
12	162.38	150.61
13	165.89	150.21
14	164.53	154.14
15	165.89	150.41
16	163.55	157.87
17	155.20	150.41
18	167.72	147.46
19	163.35	154.14
20	171.34	152.38
21	169.06	154.34
22	159.44	157.28
23	168.50	152.77
24	171.80	163.55
25	163.43	148.84
26		160.42
27		146.48
28		152.57
29		154.54
30		148.44
31		150.21
32		152.57
33		167.84
34		158.46
35		149.03
36		169.01
37		159.05
38		158.07
39		159.90
40		157.94
41		158.92
42		159.90
43		158.92
44		157.75
45		165.77
46		158.14
47		157.36
48		161.13
49		150.28
50		163.04
Mean (J)	162.83	155.89
Standard deviation (J)	5.53	5.66
RSD (%)	3.40	3.63

Annex 2



JOINT RESEARCH CENTRE
Institute for Reference Materials and Measurements

CERTIFICATE OF ANALYSIS

ERM[®] - FA415s

STEEL CHARPY V-NOTCH TEST PIECES		
	Impact toughness	
	Certified value ²⁾ [J]	Uncertainty ³⁾ [J]
Absorbed energy (KV) ¹⁾	157.3	1.4
<p>1) The absorbed energy (KV) is procedurally defined and refers to the impact energy required to break a V-notched bar of standardised dimensions, as defined in ISO 148-1. The certified value is only valid for strikers with a 2 mm tip radius and in the temperature range of (20 ± 2) °C.</p> <p>2) The certified value is estimated as the mean of means of absorbed energies measured on 7 pendulums in 5 different laboratories. On each pendulum, 20 test pieces were broken. The pendulums used are regularly verified with equipment that is calibrated in a manner that is traceable to the International System of Units (SI). Therefore, the certified value is traceable to the International System of Units (SI).</p> <p>3) Standard uncertainty u of the certified mean absorbed energy of batch ERM-FA415s, estimated as the standard error of the mean of the 7 pendulum mean values, corresponding with a confidence level of about 68 %, as defined in the ISO/IEC Guide 98-3:2008; Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM). The number of degrees of freedom of the certified uncertainty, $\nu_{RM} = 6$.</p>		

This certificate is valid until December 2021.

NOTE

European Reference Material ERM[®]-FA415s was produced and certified under the responsibility of the Institute for Reference Materials and Measurements of the European Commission's Joint Research Centre according to the principles laid down in the technical guidelines of the European Reference Materials[®] co-operation agreement between BAM-IRMM-LGC. Information on these guidelines is available on the internet (<http://www.erm-crm.org>).

Accepted as an ERM[®], Geel, July 2012
Latest revision: September 2012

Signed: _____

Prof. Dr. Hendrik Emons
European Commission
Joint Research Centre
Institute for Reference Materials and Measurements
Retieseweg 111
B-2440 Geel, Belgium



Registration No. 268-RM
ISO Guide 34 for the
production of reference materials

All following pages are an integral part of the certificate.

Page 1 of 3

DESCRIPTION OF A CRM UNIT

A unit consists of five Charpy V-notch test pieces, which are rectangular steel bars of nominal dimensions 55 mm x 10 mm x 10 mm, with one V-notch, accurately machined to tolerances imposed in ISO 148-3. The five specimens are packed together in a plastic bag filled with oil to prevent oxidation.

METHOD USED FOR CERTIFICATION

Charpy pendulum impact tests in accordance with ISO 148-1, using pendulum impact machines with a 2 mm striker tip radius.

PARTICIPANTS

Processing

- Cogne Acciai Speciali, Aosta, IT: production of steel bars
- Aubert & Duval, Gennevilliers, FR: heat treatment of steel bars
- Laboratoire National de Métrologie et d'Essais (LNE), Trappes, FR: processing of the V-notch test pieces

Characterisation

- Exova, Emmen, NL (RvA testen L085)*
- Bundesanstalt für Materialforschung und -prüfung (BAM), Division 9.1 Random Loading Fatigue and Structural Integrity, Berlin, DE (DGA-PL-2614.16)*
- Centro de Apoio Tecnológico a Indústria Metalomecânica (CATIM), Laboratório de Ensaios, Porto, PT (IPAC L009)*
- Fraunhofer Gesellschaft, Institut für Werkstoffmechanik, Freiburg, DE
- European Commission Joint Research Centre (JRC), Institute for Reference Materials and Measurements, Geel, BE (BELAC 268-Test)*
- Laboratoire National de Métrologie et d'Essais, Charpy Laboratory, Trappes, FR (COFRAC SMH 2-1287)*
- National Institute of Standards and Technology (NIST), Materials Reliability Division, Boulder, USA
- SCK-CEN, Labo Reactormaterialenonderzoek, Mol, BE (BELAC 015-Test)*
- SIRRIIS, Beproevinglaboratorium Gent, Zwijnaarde, BE (BELAC 232-Test)*
- Universität Stuttgart, Materialprüfungsanstalt, Stuttgart, DE (DAP-PL-2907.02)*

* Measurements within the scope of accreditation to ISO/IEC 17025.

SAFETY INFORMATION

Precautions need to be taken to avoid injury of the operator by broken specimens when operating the Charpy impact pendulum.

INTENDED USE

Test pieces of ERM-FA415s correspond with the '(certified) BCR test pieces' as referred to in (the now obsolete) EN 10045-2 (Method for the verification of impact testing machines), as well as with the 'certified reference test pieces' as defined in ISO 148-3 (Preparation and characterisation of Charpy V reference test pieces for verification of test machines).

The ERM-FA415s batch is one of the 'Master Batches'. Master Batch test pieces are not for sale. They are intended solely to traceably certify Secondary Batches of the same nominal absorbed energy (here 150 J). The certified value of the Master Batch, and its associated uncertainty, are used in the calculation of the certified value and combined and expanded uncertainty of a unit of 5 specimens from a Secondary Batch. Because the certified value of the Master Batch, and its uncertainty, are intermediate values, the standard uncertainty was not expanded to the 95 % confidence level, thereby avoiding unnecessary rounding effects.

When characterising a secondary batch, a number of Master Batch test pieces are broken under repeatability conditions together with a selection of test pieces from the secondary batch.

INSTRUCTIONS FOR USE

Special attention is drawn to the cleaning and conditioning of the specimens prior to testing. It is mandatory to remove the oil from the test piece surface prior to testing, without damaging the edges of the test piece. Between the moment of removing the protective oil layer and the actual test, corrosion can occur. This must be avoided by limiting this period of time, while keeping the test piece clean.

The following cleaning and conditioning procedure is considered to be good practice.

1. First use absorbent cleaning-tissue to remove the excess oil. Pay particular attention to the notch of the test piece, but do not use hard (e.g. steel) brushes to remove the oil from the notch.
2. Submerge the test pieces in technically pure ethanol for about 5 minutes. Use of ultrasonication is encouraged, but only if the edges of the test pieces are prevented from rubbing against each other. To reduce the consumption of solvent, it is allowed to make a first cleaning step with detergent, immediately prior to the solvent step.
3. Once test pieces are removed from the solvent, only manipulate the test pieces wearing clean gloves. This is to prevent development of corrosion between the time of cleaning and the actual test.
4. Before testing, bring the specimens to the test temperature (20 ± 2 °C). To assure thermal equilibrium is reached, move the specimens to the test laboratory at least 3 h before the tests.

After cleaning and equilibration, the test pieces need to be broken with a pendulum impact test machine operated in accordance with ISO 148-1, including the correction of the raw data for friction. Prior to the tests, the anvils must be cleaned. It must be noted that Charpy test pieces sometimes leave debris on the Charpy pendulum anvils. Therefore, the anvils must be checked regularly and if debris is found, it must be removed.

STORAGE

Specimens should be kept at room temperature (18 ± 5) °C in their original packing until used. The European Commission cannot be held responsible for changes that happen during storage of the material at the customer's premises, especially of opened units.

LEGAL NOTICE

Neither the European Commission, its contractors nor any person acting on their behalf:

(a) make any warranty or representation, express or implied, that the use of any information, material, apparatus, method or process disclosed in this document does not infringe any privately owned intellectual property rights; or

(b) assume any liability with respect to, or for damages resulting from, the use of any information, material, apparatus, method or process disclosed in this document save for loss or damage arising solely and directly from the negligence of the Institute for Reference Materials and Measurements of the European Commission's Joint Research Centre.

NOTE

A detailed technical report is available on www.irmm.jrc.be. A paper copy can be obtained from the Joint Research Centre, Institute for Reference Materials and Measurements on request.

European Commission – Joint Research Centre
Institute for Reference Materials and Measurements (IRMM)
Retieseweg 111, B - 2440 Geel (Belgium)
Telephone: +32-(0)14-571.722 - Fax: +32-(0)14-590.406

European Commission

EUR 26239 EN – Joint Research Centre – Institute for Reference Materials and Measurements

Title: The certification of the absorbed energy (150 J nominal) of Charpy V-notch reference test pieces for tests at 20 °C: ERM[®]-FA415ab

Author(s): G. Roebben, A. Dean, A. Lamberty

European Commission, Joint Research Centre, Institute for Reference Materials and Measurements (IRMM), Geel, Belgium

Luxembourg: Publications Office of the European Union

2013 – 22 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424

ISBN 978-92-79-33891-5

doi:10.2787/84027

Abstract

This certification report describes the processing and characterisation of ERM[®]-FA415ab, a batch of Charpy V-notch certified reference test pieces certified for the absorbed energy (KV) for tests at 20 °C. Sets of five of these test pieces are used for the verification of pendulum impact test machines according to ISO 148-2 (Metallic materials - Charpy pendulum impact test – Part 2: Verification of testing machines).

The absorbed energy (KV) is procedurally defined and refers to the impact energy required to break a V-notched test piece of standardised dimensions, as defined in ISO 148-1. The certified value of ERM[®]-FA415ab is traceable to the SI, via the SI-traceable certified value of the master batch ERM-FA415s, by testing samples of ERM[®]-FA415ab and ERM[®]-FA415s under repeatability conditions on an impact pendulum verified and calibrated with SI-traceably calibrated tools. The certified value is valid only for strikers with a 2 mm tip radius. The certified values are valid at (20 ± 2) °C.

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security, including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

ISBN 978-92-79-33891-5

